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AFCRL Tethered-Balloon Programs

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XII. AFCRL Tethered-Balloon Programs

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Abstract

A summary of current AFCRL tethered balloon programs is presented. Tethered balloon configurations, test instrumentation, and associated equipment, including experimental cables, are discussed. AFCRL planned programs which are intended to increase the state-of-the-art are summarized as are the potential applications for these systems.

1. INTRODUCTION

Within the spectrum of current interest in scientific ballooning there exists a small but significant bandwidth of technology devoted to tethered balloons. Historically, free and captive balloons were closely related through the use of the same materials. However, ever since the first flight of a free balloon constructed of polyethylene, research related to free balloons has been directed toward increasing the altitude and payload range of these vehicles by developing strong, lightweight, and inexpensive films and by refinement of the basic shape to enable them to escape the lower regions of the atmosphere. Meanwhile, tethered-balloon research has primarily been devoted to developing balloons with aerodynamic shapes that will perform well in denser environments. Whereas a free balloon is essentially an aerostatic problem with balloon weight an important factor, tethered-balloon design involves aerodynamic considerations in which balloon weight is sacrificed for vehicle strength and reuse.

Tethered balloons are potentially useful in a number of applications which have not changed significantly since 1926 when Charles de Forest Chandler (Upsom and Chandler, 1926) classified them as observational, meteorological, and signaling. Restated in current vernacular, tethered balloons may be applied as surveillance or reconnaissance platforms, be used to support meteorological experiments, and for communications relay. Indeed, there are current examples of proposed or developed tethered-balloon systems that fall into each of these categories (Honeywell Aeronautical Division, 1962; Elliot, 1964; Goodyear Aerospace Corp., 1965). It is significant that most of the development of tethered-balloon systems in the past few years has been as a result of specific atomic-age requirements, for example, air sampling, post-nuclear-attack communications, and nuclear-blast simulation, to name but a few. Other uses can easily be imagined.

2. BACKGROUND OF TETHERED-BALLOON DEVELOPMENT

Before outlining the historical development of tethered balloons, a brief description of the motivation for the AFCRL interest is in order. Early in 1963, this Laboratory responded to the increase in interest in tethered balloons and to inquiries from other agencies and potential in-house users by supporting a tethered-balloon study. This modest, in-house effort was initiated to provide experience and useful data relating to tethered-balloon shapes. The most important objective of these tests was to prepare this Laboratory to provide support and guidance based on actual experience with tethered balloons.

Concurrent with this development, an interest in higher-altitude tethered-balloon systems was being expressed at a higher Department of Defense level, and a group of feasibility studies was supported to study this problem. These studies (classified as to use areas) concluded that higher-altitude tethered-balloon systems appeared to be within the present state-of-the-art if certain limitations were recognized. It was felt that future efforts to develop tethered-balloon systems to perform above the high dynamic-pressure region would be substantially aided by preliminary work in the lower altitude range. Therefore, the Laboratory extended its development program to include a captive-balloon system designed to carry 200 lb to 12,000 ft MSL, and to operate in trade-wind latitudes. Such a system would provide an insight into some of the problems likely to be experienced in efforts to develop higher-altitude tethered balloons, and would, as well, create a useful platform-altitude and payload capability to operate in other low-wind areas, should the techniques prove successful.

To solve the problem of tethering balloons at very high altitudes, more work will be done in the near future. There are numerous areas in which research must be accomplished before an operational system is developed, and it is expected that much of the future work of this Laboratory will be applied to these areas.

The current AFCRL programs related to tethered balloons fall into three categories: the low-altitude test program, the 12,000-ft system, and the high-altitude program. I shall now describe each of these programs more fully.

3. LOW-ALTITUDE TETHERED-BALLOON PROGRAM

3.1 Background

The low-altitude test program evolved from the need to gain handling experience and to determine basic balloon parameters by using balloons of modest size. Analyses using models are unsuitable because handling experience is not gained when the testing balloons are too small. Furthermore, it can be shown that dynamic similarity cannot be achieved by using model balloons in air (Waters, 1956). For these tests, therefore, a 90-lb payload was selected, and the tether altitude was established at 1500 ft above the ground at the AFCRL Balloon R&D Test Branch, Holloman AFB, New Mexico (elevation 4090 ft MSL).

Three major types of tethered balloons were considered as test vehicles in this program: balloons of non-aerodynamic shapes, the kite balloon, and other buoyant-lifting vehicles with high lift-to-drag characteristics. These balloons are representative of the historical development of tethered-balloon shapes – early tethered balloons were spheres or onion shapes (with highest volume per unit surface area, but also highest unit surface area presented for drag, per unit volume). Later shapes were compromise configurations that were developed from attempts to provide both aerodynamic and volumetric efficiency.

3.2 Historical Development

Early streamlined shapes were essentially cylinders with hemispherical ends and a trailing steering bag to provide stability. The first kite-shape captive balloon of this category was the "drachen" produced by German Army Captains

Parseval and Sigsfeld in 1893 (Upsom and Chandler, 1926). These balloons were constructed with ram air ballonets, or internal air bags which were ram air inflated, to maintain a rigid balloon shape. They were generally used as manned observation platforms. This type of balloon was superceded by a balloon shape designed by the Section d'Aerostation of the French Army, under the direction of a Commander Caquot.

The Caquot design was adopted by the Allies in World War I and by the Germans who captured a British "captive" that had broken away. These designs were given letter designations, and major design changes consisted of elimination of the tail steering bags and conversion to a three-lobe, air-inflated system which served as the horizontal and vertical fins. Balloons of this type were also used as observation platforms in World War I, and numerous modifications of the basic shape were made (Upsom and Chandler, 1926). Examples of these configurations were the Type R (U. S. Army Observation) and the Type M (U. S. Naval Observation).

Early balloons which employed the dilation or expandable-gore technique to accommodate volumetric changes due to changes in altitude were the barrage balloons. These balloons were essentially modifications of the Type R shape, but were unmanned and used as protection against enemy air attack.

A later captive-balloon configuration of interest, the A. P. type, was developed for use by the Italian Air Force by Major of Engineers Luigi Avorio and Dr. Eugenio Prassone. It combined the volumetric efficiency of a sphere with the aerodynamic stability of a shaped balloon. The design consisted of a modified ellipsoidal form with fins attached to the trailing end to provide stability. Balloons of this type incorporated a ballonet system and were reported to have excellent stability in high winds, but an undesirable amount of downwind displacement. The A. P. types were flown as manned observation platforms and were able to reach altitudes as high as 5000 ft.

In the years following their widespread use in World War I, only relatively limited use was made of captive balloons. Aerodynamic shapes were refined, primarily, as a result of extensive wind-tunnel testing of dirigible shapes and of "cut and try" methods for designing tethered-balloon shapes for actual flight tests.

The U.S. Navy and the Royal Aircraft Establishment were primary supporters of these studies (Bateman and Jones, 1932; Zahm et al, 1927), and kite-balloon design today is still based on the "Navy Class C", a dirigible shape that was extensively tested in wind tunnels (Waters, 1956).

3.3 Low-Altitude Tethered-Balloon Shapes

The tethered balloons in the AFCRL low-altitude test program are listed by shape and described below.

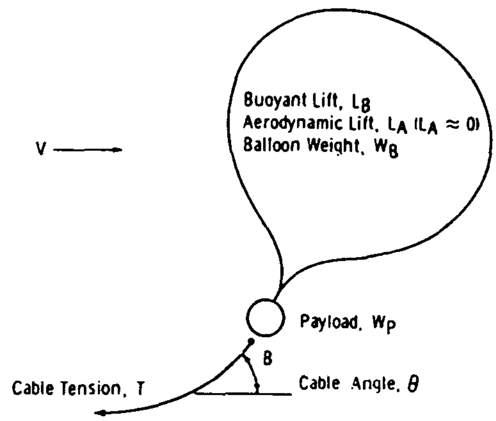
3.3.1 NATURAL SHAPE

Figure 1 shows the natural-shaped balloon designed and built by the G. T. Schjeldahl Company. It has a volume of 5570 cu ft and a gross lift of 300 lb at an altitude of 7000 ft MSL. Other characteristics are: $\Sigma = 0.05$; gore length $(S\lambda) = 35$ ft; and weight, 43 lb. The balloon is constructed of GT-31 film, which is a Dacron-Mylar bilaminate weighing about 2.5 oz/yd^2. A balloon of this configuration was desired in this program because aerodynamic drag coefficients for fully inflated natural shapes have not been experimentally determined.

An analysis to determine the drag coefficient of nonaerodynamic shapes is shown in Figure 2. As can be seen, this determination is a function of the Reynolds number, N_R, and the aerodynamic lift coefficient is assumed to be zero.

Figure 1. Natural-Shaped Tethered Balloon

For a vehicle tethered in a uniform wind of velocity V and density ρ, carrying a payload W_P, shown below.



since T does not increase significantly until θ becomes small

$$C_D = \frac{T\cos\theta}{0.5\rho\ V^2\ (Vol)^{2/3}} \quad \text{and} \quad C_L \approx 0.$$

Normally $C_D = f(N_R)$ where the Reynolds number is

$$N_R = V d \frac{\rho}{\mu},$$

where

$$d = (Vol)^{1/3}$$

and

$$\frac{\mu}{\rho} = \eta \text{ (Kinematic Viscosity).}$$

Figure 2. Aerodynamic Coefficients for Non-Aerodynamic-Shaped Balloons

3.3.2 KITE BALLOON SHAPE

The kite balloon shown in Figure 3 is a Navy Class C shape with a fineness ratio of 3.5 to 1. This balloon was manufactured by Viron Division of Geophysics Corp. of America. It has a volume of 14,080 cu ft and a gross lift of 788 lb at the design altitude of 5600 ft MSL. The balloon has a length of 70 ft, a maximum diameter of 20 ft when pressurized, and weighs about 500 lb. The balloon fabric is a 7.2 oz/yd^2 polyurethane-coated nylon. An internal ballonet is used to maintain balloon pressure. The volume of this ballonet is regulated by a pressure-switch-controlled ballonet blower and relief valve mounted in the lower aft section of the balloon. Helium-pressure relief and quick-deflate valves are also incorporated in the design to limit balloon internal pressure and to provide for deflation. The balloon flies at an angle of attack that is preset by the harness lines (generally 8 to 10 deg).

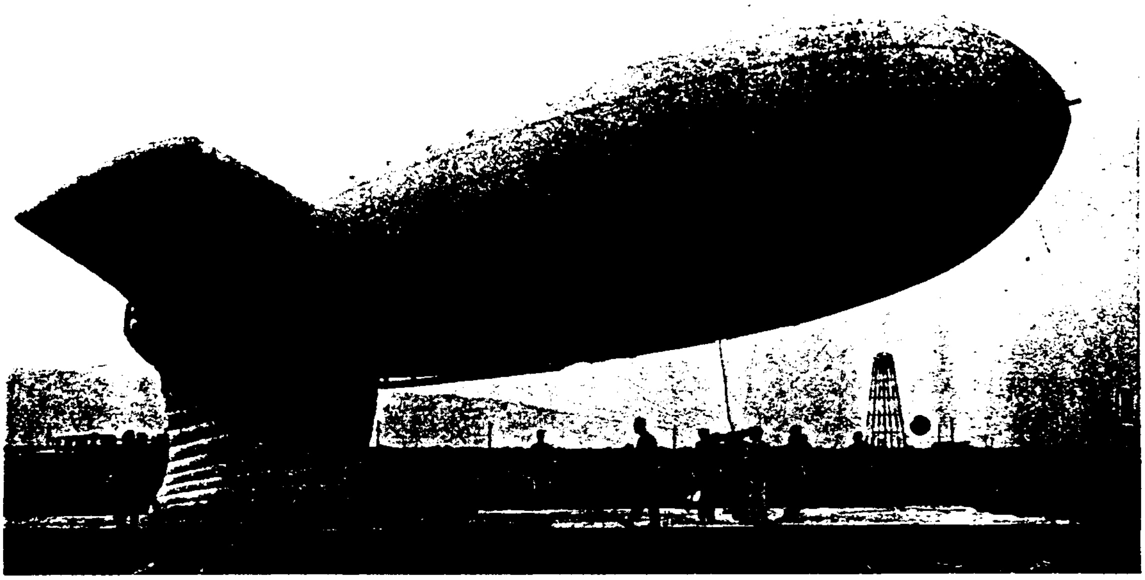


Figure 3. Kite Balloon

3.3.3 OTHER AERODYNAMIC SHAPES

The Vee Balloon shown in Figure 4 is a product of the Goodyear Aerospace Corporation. This is a twin-hulled vehicle which, by virtue of its flat shape, has a large surface area for lifting purposes and yet presents a minimum cross section to the wind. The Vee balloon has a hull length of 48.75 ft and a maximum hull diameter of 11.5 ft. Its volume is 6478 cu ft, and gross lift is 346 lb at 5600 ft MSL. The material used in construction is a Mylar-Dacron laminate coated with aluminized polyurethane. This composite weighs 5.5 oz/yd^2. The balloon is designed with two dilation sections which provide for volume changes. During flight, the angle of attack also varies with the wind velocity so that at low wind speeds aerodynamic lift is maximized, whereas in high winds the aerodynamic lift is limited to keep tether-line tensions low.

In addition to the Vee-balloon shape, another unique tethered-balloon concept is being investigated. The Buoyant-Wing Tethered Vehicle shown in Figure 5 is a configuration designed by Sea-Space Systems. The proposed design is an optimization of balloon weight (approximately 50 lb) and lifting characteristics (comparable to a Regallo Wing). This balloon will be designed to carry a 90-lb payload to 5600 ft MSL, and will be approximately 33 ft long with a span of 29 ft in flight. The planform area will be 770 ft^2.

Figure 4. Vee Balloon

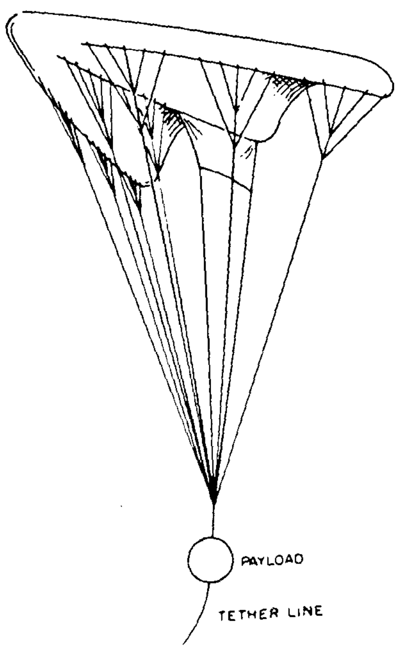
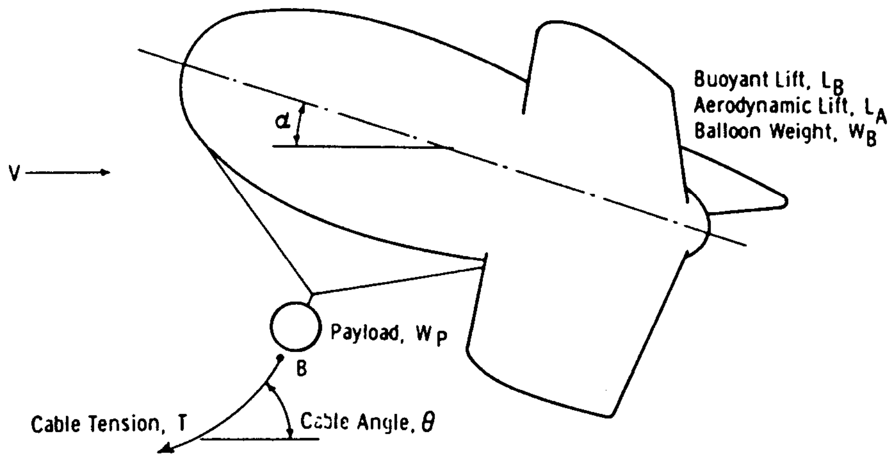


Figure 5. Buoyant-Wing Tethered Vehicle

For a vehicle tethered in a uniform wind of velocity V and density ρ, carrying a payload W_P, shown below,



at point B, a summation of forces yields

$$T_y = T \sin\theta = L_B + L_A - (W_P + W_B)$$

$$T_x = T \cos\theta\ .$$

The aerodynamic drag coefficient, C_D, is given as

$$C_D = \frac{T \cos\theta}{0.5\rho\ V^2 (\mathrm{Vol})^{2/3}} = f(\alpha).$$

The aerodynamic lift coefficient, C_L, is given as

$$C_L = \frac{T \sin\theta + W_P + W_B - L_B}{0.5\rho\ V^2 (\mathrm{Vol})^{2/3}} = f(\alpha).$$

and

$$L/D = C_L/C_D = \tan\theta\ ,\ \text{for balloons where } W_P + W_B - L_B \approx 0.$$

Figure 6. Aerodynamic Coefficients for Aerodynamic-Shaped Balloons

An analysis of aerodynamic-shaped tethered balloons to determine their aerodynamic parameters is shown in Figure 6. In both cases, lift and drag coefficients are functions of the balloon angle of attack, and, for balloons with a small amount of net static lift compared to the total amount of aerodynamic lift generated, the quotient $C_L/C_D \approx \tan\theta$.

In order to evaluate the aerodynamic coefficients of these tethered-balloon shapes, it is necessary to measure and record continuous data for wind velocity, cable tension, and cable angle, and to correlate these data with angle of attack and air density. The instrumentation designed to do this is shown in Figure 7.

Figure 7. AFCRL Test Instrumentation

4. TEST INSTRUMENTATION

4.1 Wind Speed

Wind speed is sensed by a wind-powered, permanent-magnet, alternating-current generator working through a rectifier in the meter movement. The anemometer is manufactured by the Belfort Instrument Company to U. S. Weather Bureau Specification 450. 615L. Pertinent characteristics are:

Model No.: 1420B Type C Wind Speed Instrument

Start Speed: 2 mph

Output: Linear to 1.65 V ac and 200 mA at 50 mph

Accuracy: ±3 percent full scale

Sensitivity: 500 ohms at full scale

The wind speed information is recorded on a chart recorder (0 to 200 mA galvanometer).

4.2 Cable Tension

The cable tension is measured with a Brewer tension load cell No. A-5KTA-10. This load cell consists of a BLH Type SPB-3-20-35 backed-resistance strain gauge with a 100-mV output for a 12-V dc, bridge input. The transducer has the following characteristics:

Strain Gauge: BLH Type SPB-3-20-35

Backed Resistance: 342.0 ohms at 77° F

Gauge Factor: 121.0

C_2: 4100 at 77°F

Bonding Cement: BLH EP4 150

Moisture Protection: RTV 732 clear

Input Resistance: 388.0 ohms

Output Resistance: 366.6 ohms

Load Indicator Calibration: 100 mV output with 12 V dc bridge input

Temperature effect on transducer zero: ± 1 percent (-75° to 100°F)

Temperature effect on transducer output: less than ± 4 percent (-75° to 100°F)

The cable tension is recorded continuously by two chart recorders. The low tensions (0 to 500 lb) are recorded on a 0 to 10 mV galvanometer, and high tensions (0 to 5000 lb) on a 0 to 100 mV device.

4.3 Cable Angle

The cable-angle indicator is a damped pendulum that is mounted on an arm that is free to pivot about an axis parallel to that of the tethered package. This device will always measure the angle of the cable in the plane of curvature of the cable. The damped pendulum consists of a 4-in. arm with a 21-oz weight attached. The pendulum is geared (12 to 1 ratio) to a 100-ohm Helipot requiring a minimum torque of 0.1 oz/in. The damping oil is SAE 40 weight oil with a viscosity of 3000 Saybold Universal Seconds (SSU) at room temperature. The cable angle is recorded on a chart recorder from 0 to 25 deg full scale. The recorder is a 0 to 100 mV galvanometer.

4.4 Safety

In addition to the measuring equipment, the test instrumentation package incorporates a three-channel Zenith Receiver to provide for safety control and system cutdown in emergency situations. (By adding an auxiliary power supply, this package is adaptable to the three balloon shapes being flown.)

4.5 Balloon Angle of Attack, and Air Density Measurement

The balloon angle of attack is obtained by using multicine-theodolites which are located on the perimeter of the test site at Holloman AFB. Target data are furnished prior to flight tests so that the theodolites can be focused on the proper area of the balloon. Azimuth and elevation angles of the balloon are calculated by a resolution of the angles read from the theodolite film. Because the apparent pitch angle observed from a station defines a plane, the line of intersection of two such planes at corresponding times defines the altitude of the target longitudinal axis. Whenever altitude-apparent pitch angles are available from more than two stations, they are adjusted in accordance with the least-squares criteria, viz.:

(1) The sum of the squares of the adjustments are a minimum, and

(2) any pair of adjusted angles yields the same result in the two-station altitude solution.

In preliminary tests the errors have been less than 0.5 deg.

The necessary value of air density, ρ, is obtained from rawinsonde information for a time closest to the flight time of the tethered balloon. Density at the mathematically defined height is determined under the assumption that temperature and pressure errors are both normally distributed and independent, which leads to a definition of density rms error of ± 3 percent (Johannesen). Air density variation during the time lapse between observation and actual flight time should be considered; it is caused primarily by the change in air temperature. Errors due to this effect can be reduced by correcting the measured air density for the change in temperature, using the "perfect gas" law.

5. TEST RESULTS

Preliminary results for flight No. H65-78, a tethered flight using the natural-shaped balloon, are shown in Table 1. The reduced data are plotted as circled points in Figure 8. This plot of the drag coefficient as a function of Reynolds number was made for the tethered, natural-shaped balloon, based on a characteristic length, d = Volume 1/3. As a comparison, the classic curve for drag coefficient for a sphere is also shown, illustrating the laminar-turbulent transition at a Reynolds number of about 2.5×10^5. At this point the drag coefficient shows a definite decrease, which is due to separation of the boundary layer, and corresponds to a shift of the stagnation points on the sphere to locations well forward of the center. The high values of drag coefficient for a tethered, natural-shaped balloon are not conclusive; more measurements are necessary, and experimental errors were not well defined. However, somewhat higher drag coefficients should be expected, and the results do indicate that a transition still occurs. No data-recording flights were flown with the aerodynamically shaped balloons.

6. OTHER COMPONENTS

A vital part of the tethered-balloon system is the cable and associated winch equipment. Early in the low-altitude, tethered-balloon program AFCRL obtained

Table 1. Field and Instrumentation Data

Time (Local)	Wind Velocity (mph)	Wind Velocity (fps)	Cable Tension (0-500 lbs)	Cable Tension (0-5000 lbs)	Cable Angle, θ	Cosine θ	Cable Out (ft)	Remarks
0627		13.2	225		78.75	0.1951	1015	
0634		9.9	212.5		80.5	0.16505	1015	
0638		8.7	200		83	0.1219	1015	
0643		11.01	212.5		82	0.1392	1015	
0646		8.7	212.5		82	0.1392	1015	
0650		8.7	192.5		81.5	0.1428	1015	

Launch Site-T2
Flight Number-H65-68
Type Balloon-Sphere
Date-11 Aug 65

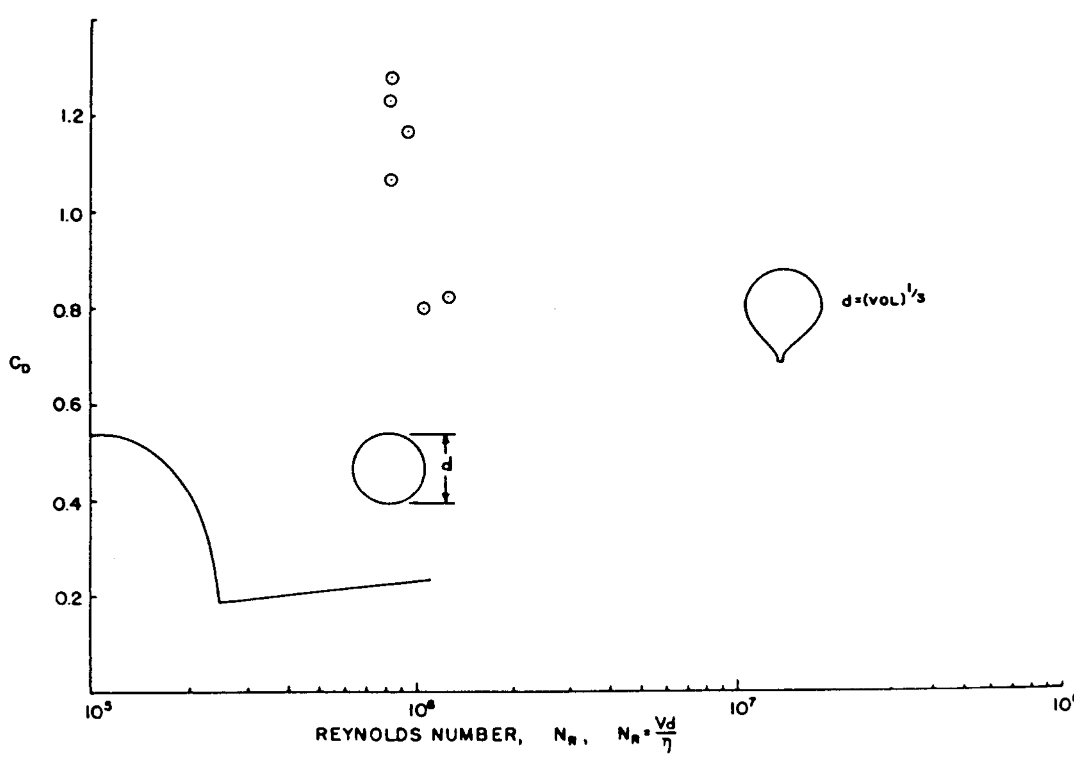


Figure 8. Aerodynamic Drag Coefficients for a Tethered Sphere

three U.S. Navy, MC-3 mobile winches. This equipment was originally designed for the Navy by Goodyear Aerospace Corporation for handling dirigibles. The unit is mobile and the winch is independently powered by a motor-generator through eddy-current clutches. The primary limitation of the equipment for tethering small balloons is simply that it was designed for much larger loads and cables. The free-wheeling mode requires a significant amount of force to overcome winch-drum inertia; therefore, this equipment will be used primarily in tests with larger balloons. A smaller unit is presently being planned which will be compatible with the small balloons I have described.

7. MEDIUM-ALTITUDE TETHERED BALLOONS

In expanding our tethered-balloon effort, AFCRL has designed and shortly will be flying a tethered system to carry 200 lb to 12,000 ft MSL. The components of this system are a hydraulic, traction-sheave winch and a 55,000 cu ft natural-shaped balloon.

7.1 Tethered-Balloon Winch

The winch shown in Figures 9 and 10 consists of: a pair of hydraulically driven traction sheaves; a hydraulically driven storage drum which leads, or lags, the traction sheaves when cable is being reeled in or paid out; and a power unit employing a Ford Industrial engine that powers two Vickers, vane-type pumps. The winch was designed to store 12,000 ft of 1/4-in.-diam cable, and to provide varying in-haul and out-haul rates, depending on the cable tensions involved. Cable is stored on the storage drum under low tensions, while high tensions are developed by the multigrooved traction sheaves. This equipment is presently mounted on a 25-ft flatbed to provide mobility, and the unit is easily transportable.

Tests were run using this winch and a unique fiberglas cable fabricated by the Packard Electric Division of General Motors Company. This cable is a 1 x 19, right-hand lay, conventional cable construction. The composite diameter is approximately 0.250 in. and the cable is coated with a U/V stabilized polyurethane to facilitate handling and to increase the cable coefficient of friction. Use of this cable on the traction-sheave winch for balloon tethering was accomplished by using the small tethered balloons described previously. Additional tethering using a reefed balloon with a gross lift of 500 to 600 lb was done. Static load tests of the cable and winch combination have developed forces of 2000 lb in both in-haul and payout modes. The cable end-fitting used on the fiberglas is potted on, and is rated at 95 percent of the full strength of the cable. Cable

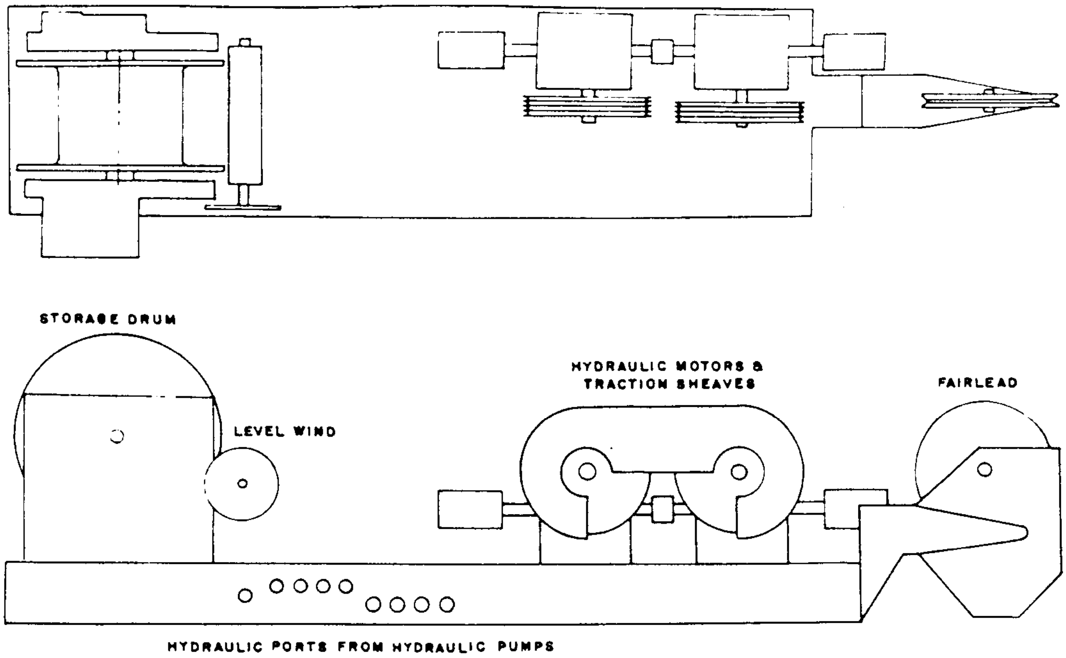


Figure 9. Balloon Tether Hydraulic Winch Configuration

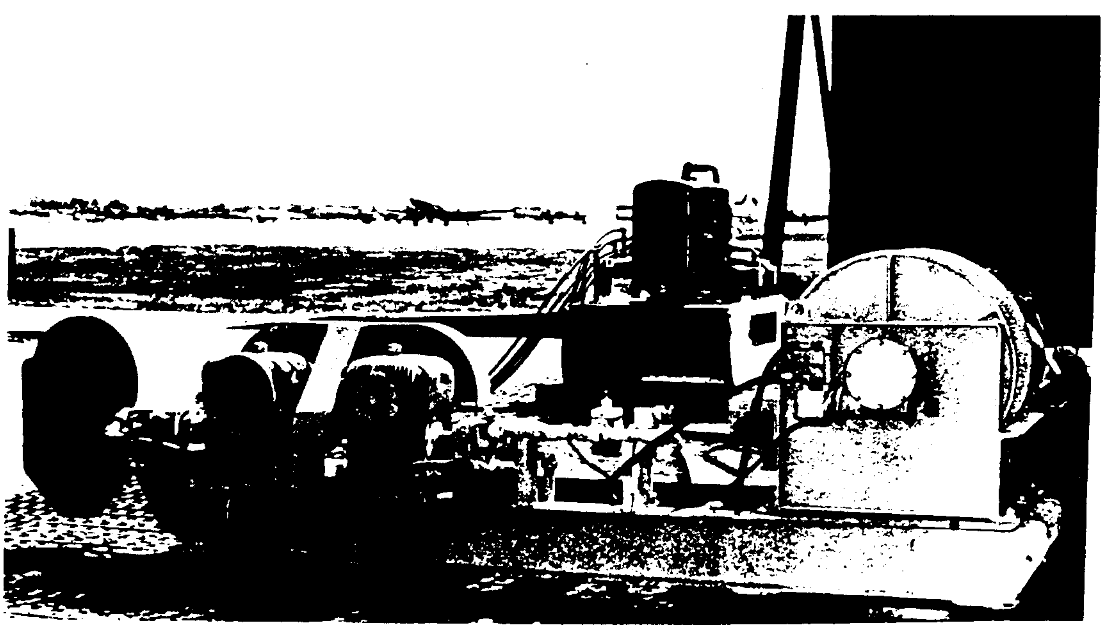


Figure 10. Balloon Tether Hydraulic Winch Configuration

strengths are on the order of 200,000 lb/in.^{2}, based on actual static tension tests. The cable has lower torque under load than conventional cable or rope, due to its inert property. This same property produces low elongation, less than 5 percent (Robertson, 1964), and other characteristics typical of brittle materials.

7.2 Tethered Balloon

In this part of the program, a natural-shaped balloon will be used with a tangent harness suspension system. The balloon volume is 55,000 cu ft, gore length (Sλ) is 75 ft, and the maximum diameter is 46 ft. The balloon configuration was designed for operation in winds less than 20 knots. It has the following advantages:

(1) low cost fabrication and use of standard hardware,
(2) high volume efficiency,
(3) lighter weight than the aerodynamic shape of equivalent volume,
(4) lower strength requirements for tether cable, and
(5) simplicity of handling and suspension rigging.

This balloon incorporates a 13-in.-diam, pressure-relief, quick-deflate valve in the top end-fitting. Excess pressure against the valve acts against a tension spring in the valve assembly and, as the valve opens, its geometric configuration offers a reduced valve-opening force. Addition of a thrust spring to this assembly allows the valve to apex when the cords retaining this spring are cut. Deflation is accomplished by activating the squib line-cutters which allow the valve to open. These squibs are fired by radio command, and independently by a preset aneroid relay closure.

An inflation assembly, a pressure tap, and a dilation-capacity warning light system are incorporated with the bottom end-fitting.

Volume changes due to the range of altitudes in which this balloon is flown are accomplished by using eight vertical dilatable sections. A capacity for 60 percent volume change is desired. The dilation system will provide for maximum pressure not exceeding material requirements, and minimum pressure above the expected dynamic pressure at 40 knots.

The balloon vehicle will be fabricated with a Tedlar-Dacron bilaminate coated with polyurethane to provide abrasion resistance. Tedlar has outstanding resistance to sunlight, and low permeability, with the ability to retain low-permeability valves after abuse. Dacron provides maximum reuse because minimum degradation in strength occurs as this material is exposed to sunlight. The fabric weight is 3.5 oz/yd^2.

Vithane 200 polyurethane provides abrasion resistance and adheres well to the Dacron. This coating will also afford some gas retention.

8. HIGH-ALTITUDE TETHERED BALLOONS

The concept of tethering a balloon at very high altitudes (altitudes above the high dynamic-pressure region of the atmosphere) holds many attractive possibilities. A few potential applications of such a system are: surveillance, reconnaissance, meteorological uses, and communications.

The most significant areas of research pertinent to the development of operational, tethered, high-altitude balloons are portrayed in Figure 11. High-altitude tethering presents quite different problems from those of the low-altitude programs I have been discussing, and it would be impractical to describe them in great detail in this paper. However, a significant difference between the

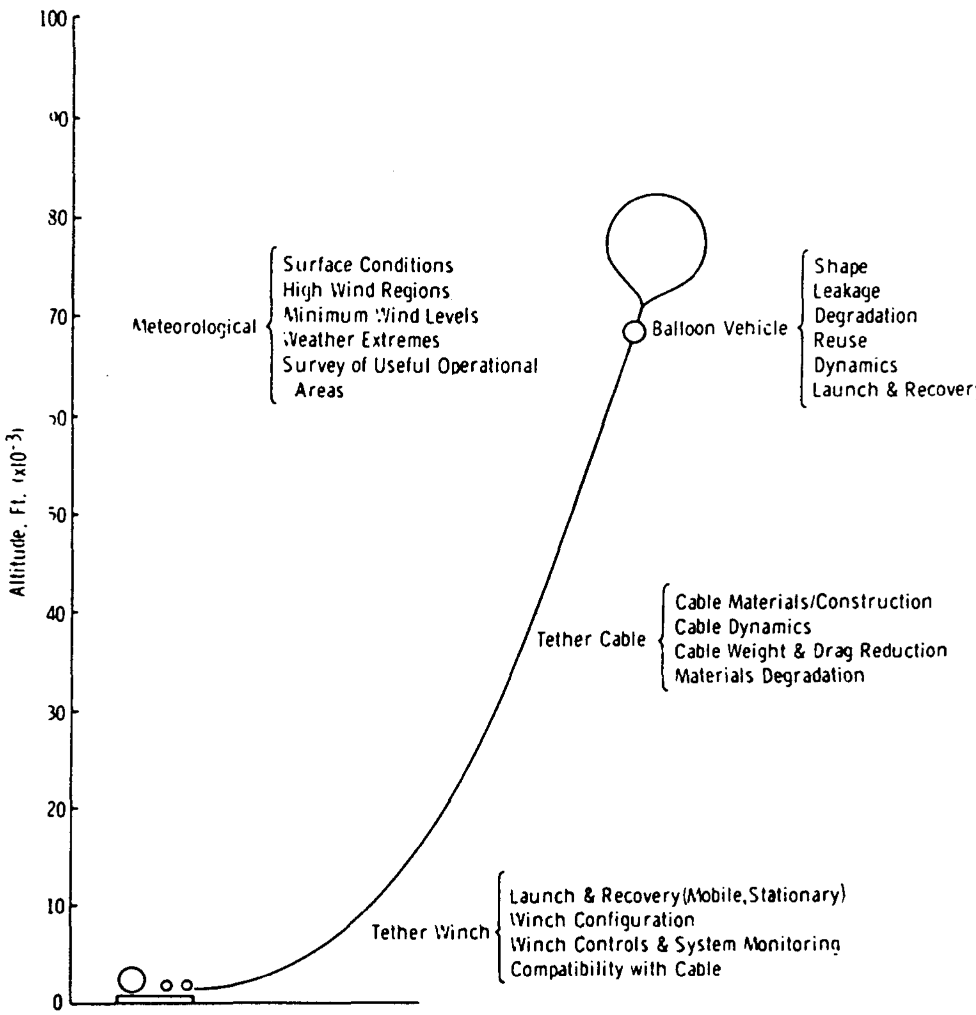


Figure 11. High-Altitude Tethered-Balloon System R&D Areas

lower- and high-altitude tethered balloons is the fact that the high-altitude captive balloons will more than likely be natural shapes and therefore will resemble the free balloons in common use. The problems of launch and recovery are closely related to the meteorological conditions which exist in the geographic area of the proposed operations.

To a large extent, the balloon size and the system drag of high-altitude systems are related to the properties of the tether cable. There are several possibilities for reducing cable weight. One solution is to work with tapered, or stepped, high-strength steel cables. Another, more attractive development is the fiberglas cable of the type described by S. D. Elliot (1964). This cable has the potential for developing strengths as high as 300,000 psi with cable strength-to-weight ratios that are significantly higher than those of other useful materials. Problems in handling fiberglas were experienced, but this area of development does not present a technical barrier. The reduction of cable drag by using aerodynamic-shaped cable is an engaging concept but constitutes a rather complex problem. This problem is being studied to determine whether such a cable can be fabricated, and to weigh the relative advantages due to drag reduction against the obvious disadvantages of special methods of cable winching and storing, costs, and questionable dynamic performance.

The study of the high-altitude tethered-balloon system will receive increasing emphasis in the near future, and work will be done in the major problem areas listed in Figure 11. It is anticipated that guidelines for future development of high-altitude tethered balloons will be established as a result of these efforts.

9. CONCLUSION

In summary, in the AFCRL low- and medium-altitude tethered-balloon programs a consistent effort is being made to advance the state-of-the-art. Low-altitude experiments should lead to useful results in evaluation of balloon shapes, and there will be extensive carryover to the medium- and high-altitude studies in terms of experience and development of promising tether cables and vehicles. The low-altitude tethered-balloon program, as established, offers another service to in-house research that can be applied to a specific problem on short notice.

It is anticipated that medium-altitude tethered-balloon work will continue with efforts made toward developing a 20,000-ft system.

The high-altitude tethered-balloon program will be definitive in nature; that is, significant problem areas will be treated in depth not heretofore completely analysed, and this research will be intended to offer guidance for future development work in this area.

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